Coastal and Near Surface Mixing

Rolf Lueck
Centre for Earth and Ocean Research
University of Victoria
Victoria, B.C., V8R 5T7
phone: (250) 721-8918 fax: (250) 721-6195 email: rlueck@uvic.ca

Award Number: N000149310362
http://george.seos.uvic.ca

LONG-TERM GOAL

My long-term goal is to contribute to our understand of turbulence and mixing processes in the ocean and to establish how mixing affects the distribution and transport of heat, salt, and other important scalars. Of particular interest to me is relating the mixing processes to the strength of currents and density stratification.

OBJECTIVES

I wish to establish how the efficiency and the rate of mixing depend upon the shear in currents, the stratification of the density and the intensity of turbulence. Mixing increases the potential energy of the ocean by raising denser water towards the surface. The efficiency of mixing is the fraction of kinetic energy that is converted to potential energy. The challenge is to measure the mixing directly without relying on models and assumptions about the nature of turbulence.

APPROACH

We are using a towed vehicle to survey the turbulence in deep tidal channels where, over the course of a tidal cycle, currents, stratification and the intensity of turbulence vary considerably. The towed vehicle (Fig. 1) carries high-resolution velocity and temperature sensors (shear probes and thermistors), current meters, a vertical array of three pairs of salinity and temperature sensors, and motions sensors. These sensors provide a measure of the density stratification, the rate of dissipation of turbulent kinetic energy, and the fluctuations of vertical velocity, salinity and temperature due to turbulent eddies. Simultaneously, we measure the vertical gradient of current using a ship-mounted acoustic current sensor (ADCP) and take profiles of salinity, temperature and density over the full water column using a CTD. The correlation of the fluctuations of vertical velocity with temperature and salinity provides a direct estimate of the vertical flux of density (hence the rate of mixing) without making any assumptions about the nature of turbulence. The ratio of this flux to the rate of dissipation of kinetic energy gives the efficiency of mixing.

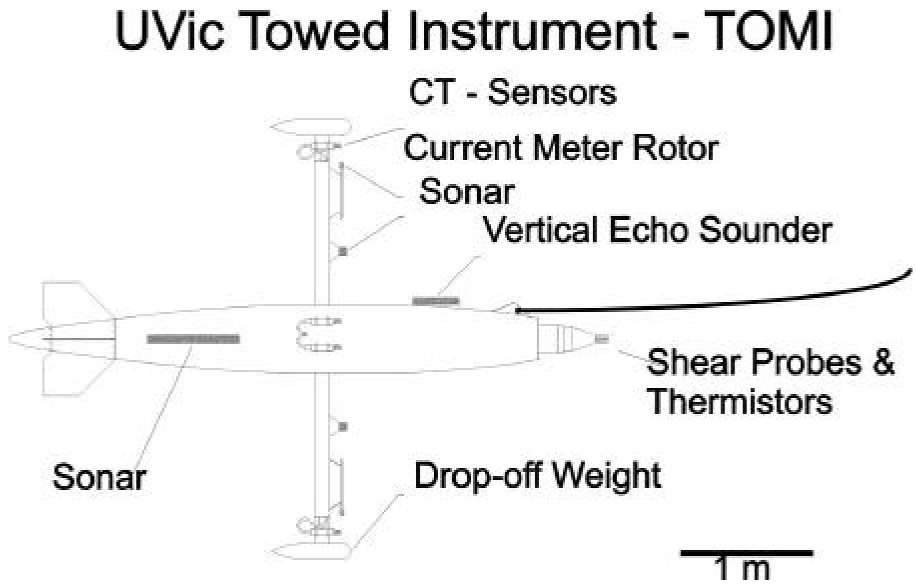

Fig. 1. The towed vehicle used for the study of mixing in Sansum Narrows. The acoustic transducers were not mounted. The conductivity (salinity) and temperature sensor at mid body was mounted close to the shear probes for of the tows and resolved the salinity fluctuations. The vehicle weighs 900 pounds in air and has an enclosed mass 800 kg when submerged.

The rate and efficiency of mixing each depend upon two parameters: the buoyancy Reynolds number (which is measured with the towed vehicle) and the Richardson number (which requires additional data from the ship-mounted ADCP). The buoyancy Reynolds number is the ratio of kinetic energy available for mixing to the potential energy stored in the density stratification. The Richardson number is a measure of the instability of the current. Both of these parameters vary by several factors of 10 over a tidal cycle and this should allow us to determine how the Richardson and buoyancy Reynolds numbers relate to the rate and efficiency of mixing.

WORK COMPLETED

We have completed the two cruise to Sansum Narrows (July 1999; August 2000) and collected a total of 80 hours of data. Additional surveys were made in Spieden Channel (San Juan Islands, Wa.) . A typical tow path is shown in Fig. 2. Our 600kHz ADCP profiled the full water depth (75-100 m) in most of the channel and bottom tracked in all parts of the channel. The year 2000 cruise had salinity flux sensors working successfully and we used a video camera mounted on the upper mast to correlate scattering layers against zooplankton abundance and turbulence intensity.

RESULTS

Figure 2 depicts the northward path of our towed vehicle during an ebb tide when the water flows southward as indicated by the arrows. Strongly stratified water enters Sansum Narrows at the north end, accelerates at the narrows and mixes as it travels southward to Satellite Channel. The current separates from the bottom at the sill between the south and middle sections and forms a free jet in Satellite Channel.

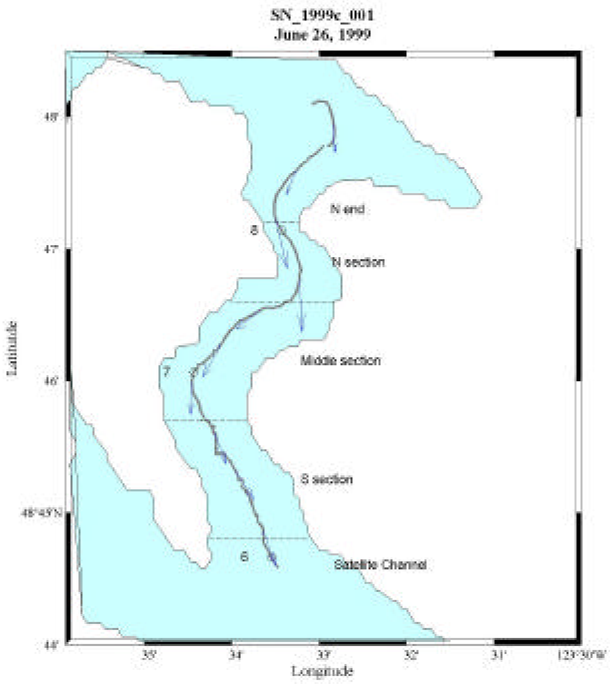

Fig. 2. A typical tow path through Sansum Narrows. The arrow indicate the strength and direction of the ebb tide. The numerals indicate the local time in hours. There is a 60 m sill along the line separating the middle and south sections.

The mean vertical shear of current is strongest in the middle section (Fig. 3, upper panel) where the density is nearly homogeneous (Fig. 3, blue curve, middle panel). The microstructure shear (dw/dx) and, hence, the rate of dissipation of kinetic energy is also largest in the middle section. The Richardson number is nearly zero in the middle section, while larger values are found in the south and the largest Richardson numbers occur in the north near the entrance to the channel (Fig.3, lower panel).

When the observations are placed into non-dimensional parameter space (Fig. 4), it is clear that conditions in the channel span over all possible values for geophysical scale flows. In the north end of the channel (green dots) the turbulence is heavily damped by stratification (buoyancy Reynolds numbers between 0.1 and 10). In the middle section (dark blue dots) the turbulence is unfettered by stratification (buoyancy Reynolds numbers reaching 10^6) and the shear is completely unstable (Froude numbers greater than 2). The transition between these regimes occurs at buoyancy Reynolds numbers of 100 to 1000.

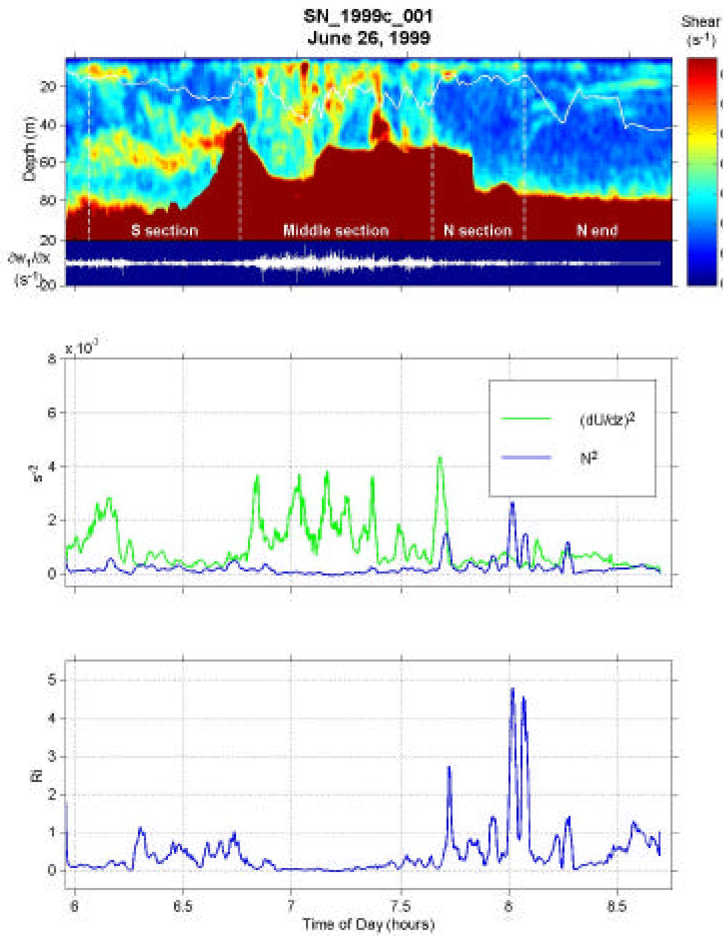

Fig. 3. (Upper panel)The modulus of vertical shear of current smoothed over 5 m vertically and 150 m horizontally along the tow path shown in Fig. 2. The white line between 10 and 40 m depth depicts the depth of the towed vehicle while the "fuzzy" white line with black background shows the microstructure shear (dw/dx). (Middle panel) The modulus of shear (green curve) and the strength of density stratification(buoyancy frequency squared) at the depth of the towed vehicle. (Lower panel) The Richardson number (or instability of the current) derived from the ratio of the two curves in the middle panel).

IMPACT/APPLICATION

Simultaneous measurements of the fluctuations of vertical velocity , salinity and temperature combined with dissipation rates and stratification have never before been made from a single vehicle. Our approach derives the fluxes of heat, salt and density directly and lends itself to the study of mixing in other environments and with other horizontally moving platforms such as autonomous underwater vehicles (AUV)s, submarines and possibly moorings. It provides a means to study the complicated motions in coastal environments resulting from strong currents that contact the bottom. The insight obtained from these and future measurements will lead to better predictions about coastal dynamics such as, for example, the dispersion of contaminants and the diffraction and scattering of high-frequency sound.

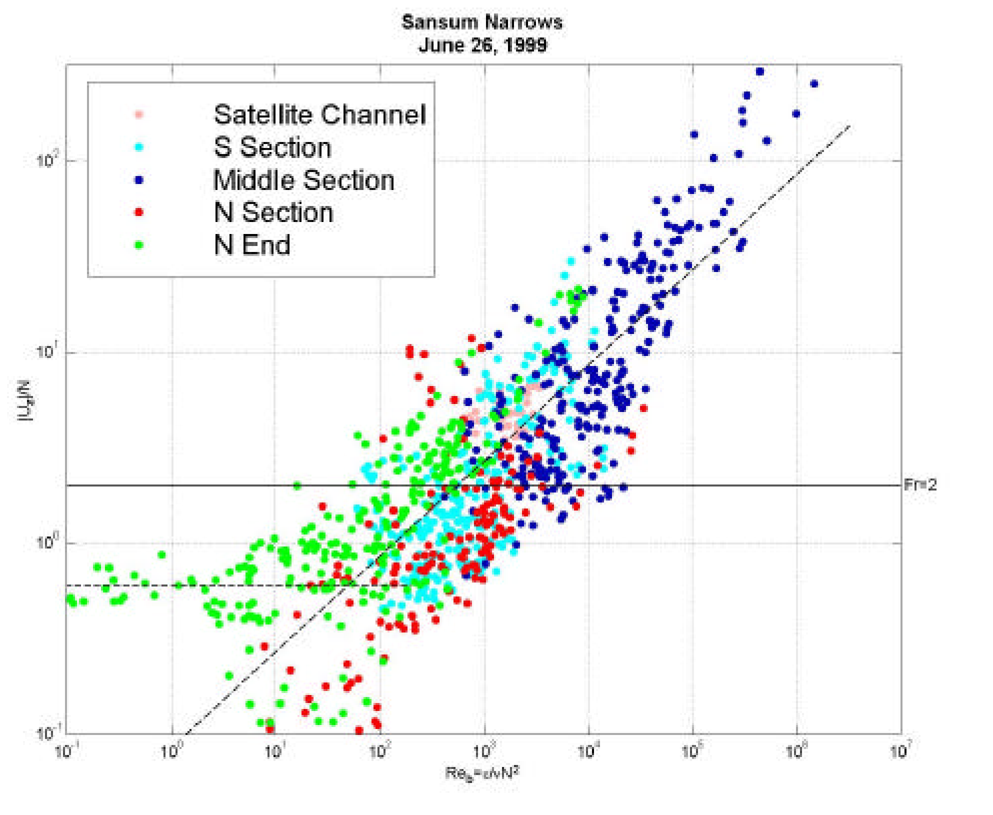

Fig. 4. The "scatter plot" of the observations shown in Figures 2 and 3 placed into dimensionless parameter space. The buoyancy Reynolds number is the ordinate while the Froude Number (the square root of the inverse of the Richardson Number) is the co-ordinate. The color of the points identifies the regions of the channel from which the observations were derived.

TRANSITIONS

The methods and techniques used for this research have been transferred to autonomous underwater vehicles (AUVs). See related projects below.

RELATED PROJECTS

1. Ed Levine of the Naval Undersea Warfare Center and I are using the small autonomous vehicles *REMUS* to study mixing processes in the New Jersey Bight and Massachusetts Bay.

2. Tom Osborn (Johns Hopkins University), Steve Thorpe (South Hampton, UK) and I are using the AUV *Autosub* to examine gravity currents on the continental slope and Langmuir circulation.

3. Manhar Dhanak (Florida Atlantic University) and I are using the *Explorer* AUV to study mixing processes in the Florida Current.

4. Hide Yamazaki (Tokyo University of Fisheries) and I are investigating the breaking of internal-wave near the bottom of the surface mixing layer and the effect of ridges that cross the Kuroshio Current south of Tokyo.

PUBLICATIONS

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